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DESIGN AND OPERATION OF ELECTRICAL CONTROL MECHANISMS IN UNDERGROUND PUMPING PLANTS

PROGRESS REPORT 1

BY

ALBERT C. DURHAM

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DESIGN AND OPERATION OF ELECTRICAL CONTROL MECHANISMS IN UNDERGROUND PUMPING PLANTS PROGRESS REPORT I[1]

By Albert C. Durham[2]

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2/ Electrical engineer, Anthracite Mechanical Mining Section, Bureau of Mines, Schuylkill Haven, Pa.

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INTRODUCTION

In anthracite mining, pumping is a problem of major importance, and water must be handled and rehandled in almost every mine whether the mine is in operation or idle. The motor-driven centrifugal pump is the most commonly used type of unit for the large pumping installations, and experience has proved that fully automatic control has certain advantages over manual control.

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Some of these advantages are greater safety for maintenance personnel, continuous protection against faulty operation, which could cause damage to the pumping apparatus, and lower pump-room operating costs.

Serious effort began in about 1922 to develop fully automatic control for mine pumps and to eliminate the human element as far as possible by replacing manually operated devices with automatic devices. The following were considered to be necessary minimum standards:

1. Prime the main pump when water in the sump reaches a predetermined high level.

2. Protect against starting the main pump until fully primed.

3. Start the main motor when the main pump is properly primed.

4. Stop the priming pump when the main pump starts.

5. Shut down the main pump in the event of faults likely to cause damage to the pump, such as a blocked suction line, excessive leak in suction line, or break in the discharge line.

6. Stop the main pump when water in the sump recedes to a predetermined low level.

With these points of view, development of automatic controls and devices as applied to mine pumping progressed to present-day designs.

The information given in this report resulted from investigation of the design and operation of two modern automatic pumping plants in the anthracite region. The first is an underground submerged-type plant, and the second is an underground open-type plant. These two plants, together with the automatic control mechanisms in use at each, are described under case I and case II, respectively, in this report.

ACKNOWLEDGMENTS

The engineers and other officials of the two mining companies whose pumping plants are described, together with representatives of the pump manufacturers, cooperated fully in the preparation of this report by giving necessary information and offering helpful suggestions.

CASE I

Description of Pumping Plant

General

This fully automatic, underground, submerged pumping plant is located immediately at the bottom of a shaft mine, approximately 485 feet below the surface. It consists of two main rooms, one on the north side and one on

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the south side of the shaft, known as the north and south pump rooms, respectively. These rooms open out from the shaft through an entrance 29 feet long, which was made by enlarging the gangway. Each room is 18 feet wide, 16 feet high, and 79 feet long. They are walled with Schaefer lining rings 18 inches thick. The floors are made of concrete slabs laid on a rock pack.

Main Pumping Units and Motors

The south pump room is equipped with two 5,200- to 6,700-g.p.m. pumps. The north pump room is equipped with one 5,200- to 6,700-g.p.m. pump at present, and plans are now being prepared for a duplicate unit in this room. All units are 14-inch, 4-stage centrifugal pumps with all-bronze casings, Duraloy chrome-iron impellers, and stainless-steel shafts, and are driven by 1,000-horsepower, 2,300-volt, 3-phase, 25-cycle, 750-r.p.m. line-start motors. Suction lines are 18-inch cast-iron pipe with bronze suction bells and bronze strainers. Discharge lines are also of 18-inch extra-heavy cast-iron pipe, each fitted with an all-bronze automatic check valve with electric contacts. The two units in the south pump room discharge into a single cast-iron wood-lined pipe with an inside diameter of 20 inches. Likewise, the two units in the north pump room are being arranged to discharge into a similar 20-inch pipe. These pipes extend from the respective pump rooms up the shaft for a distance of approximately 375 feet. At this point each cast-iron pipe is connected to an all-wood pipe with an inside diameter of 20 inches. These all-wood pipes extend up the remaining distance of approximately 110 feet to the surface. The 20-inch wood pipe from the north pump room connects at the surface to a 24-inch-inside-diameter wood-stave pipe that extends approximately 1,700 feet to the river. The 20-inch pipe from the south pump room connects at the surface to a 36-inch-diameter, cast-iron wood-lined pipe and extends toward the river for a distance of approximately 185 feet. From this point the water is carried to the river in a 6-foot-diameter open flume.

Electric Power Feeders

The incoming electric feeders extend from a 23,000/2,300-volt surface substation down a 12-inch borehole to the north pump room. In the present borehole there are three 3-conductor, 600,000-c.m., 5,000-volt, rubber-insulated armored cables.

A second borehole with three 3-conductor, 500,000-c.m. cables is now being installed for use in case of emergency. The spare cables have the same current-carrying capacity as the original 600,000-c.m. cables because the insulation is of a heat-resistant synthetic rubber instead of the Para-rubber insulation used on the original cables.

Auxiliaries

Each pump room is equipped with (a) one 5,000-c.f.m. ventilating fan driven by a 5-horsepower, 440-volt motor; (b) one 25-kv.-a., 3-phase power transformer tapped for 440 and 220 volts to provide power to the auxiliary and priming pumps and to the various control circuits; and (c) one 7-1/2-kv.-a., single-phase transformer to supply the 110-volt lighting and alarm

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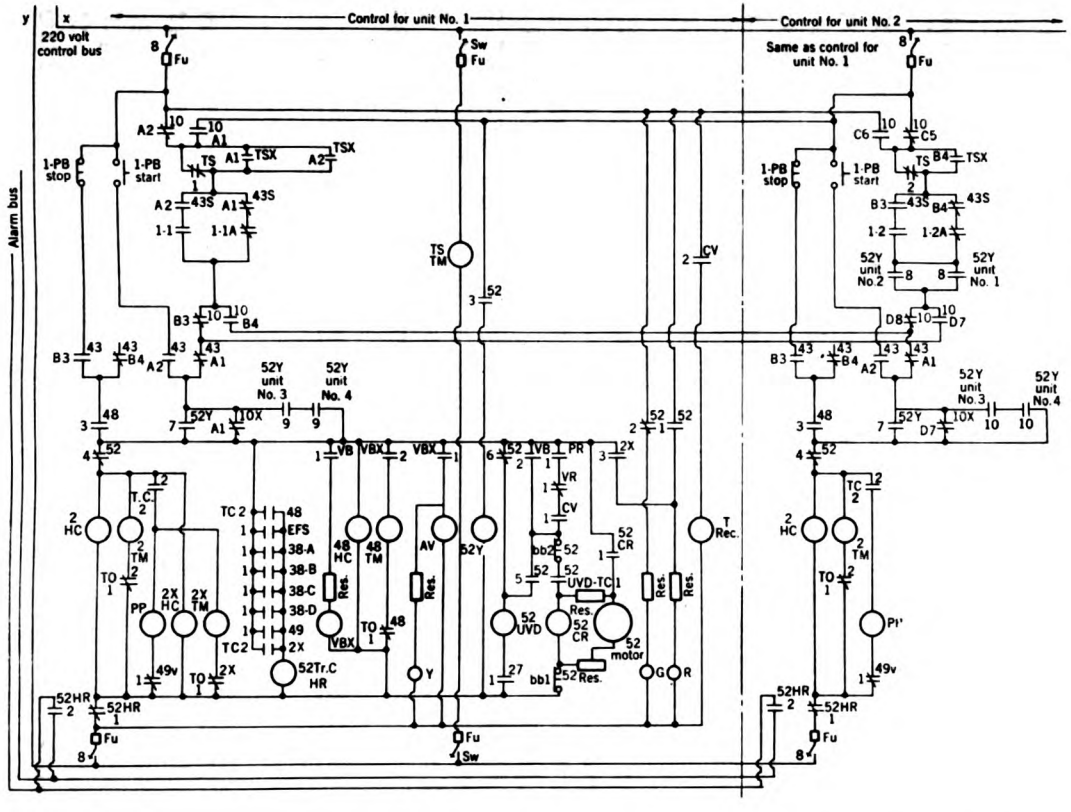

Terminology			
No. //	Device	Abbr.	Device
1-1	Pressure switch, high level suction head	AV	Air valve solenoid
1-1A	Vacuum switch, low level suction lift	CR	Control relay
1-2	Pressure switch, high level suction head	CV	Check valve contact
1-2A	Vacuum switch, low level suction lift	EFS	Emergency float switch
1-PB	Push button	Fu	Fuse
2	Time delay starting relay	G	Green lamp
2x	Priming time limit relay	HC	Holding coil
8	Control power switch	HR	Hand reset
10	Unit sequence transfer switch	PP	Priming pump motor starting relay
10X	Pumproom sequence transfer switch	PR	Discharge pressure regulator contact
27	Undervoltage and reverse phase relay	R	Red lamp
38	Bearing thermal relay	Res.	Resistance
43	Transfer switch, manual to automatic	Sw	Switch
43s	Transfer switch, suction head to suction lift	TC	Time close contact
48	Incomplete sequence timing relay	TO	Time open contact
49	A. C. thermal relay, hand reset	TM	Timing motor
49v	Thermal relay for priming pump	Tr.C	Trip coil
51	A. C. overcurrent relay	T. Rec.	Time recorder
52	Oil circuit breaker and mechanism	TS	Time switch
52Tr.CHR	Hand reset contacts on No. 52 mechanism	TSX	Auxiliary switch to TS
52UVD	Undervoltage device on No. 52 mechanism	VB	Vacuum breaker contacts
52Y	Auxiliary relay for No.52	VBX	Auxiliary relay for VB
52bb	Oil circuit breaker auxiliary contact	VR	Vacuum regulator contact
		Y	Yellow lamp

Graphical symbols //	
Contact Normally open	Contact Normally closed
Contact Time close T. C. Normally open	Contact Time open T. C. Normally closed
Relay coil	Resistor Res.

// In accordance with standards established by the American Standards Association

Figure 1. - Automatic pumping control circuit diagram, case 1.

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circuits. The 7-1/2-kv.-a. transformers are interconnected, so that either transformer can be used to supply 110-volt power to both pump rooms, but are not operated in parallel. Each main pumping unit is equipped with a 50-c.f.m. automatic priming pump driven by a 5-horsepower, 440-volt motor.

One auxiliary 250-g.p.m. centrifugal pump driven by a 15-horsepower, 440-volt motor is installed in the airway between the two pump rooms to remove any water leaking into the pump rooms. This unit, equipped with 8-inch suction and discharge lines, is designed for a 110-foot head. Water that seeps into the pump room is returned to the main body of water.

Metering

All electric metering is accomplished at 2,300 volts through suitable instrument transformers. The control panel for each of the main pumping units is provided with an ammeter and a wattmeter to measure the power used by the individual pumps. In addition, the total power used in each pump room, including all auxiliaries for that room, is measured with an ammeter, voltmeter, wattmeter, and watt-hour meter. Each main pump is provided with an electric time recorder, which makes a time record of the period each pump is actually pumping water.

Protective Features

The 2,300-volt incoming feeders are connected in each room to a 2,300-volt bus through group-operated disconnecting switches and manually operated automatic-trip oil circuit breakers. The electric power system is protected, so that in the event of a power failure and restoration the pumps will not all start at once, but in proper sequence. This protects against excessive power peaks being drawn from the system, such as would accompany the starting of more than one pump of such size at the same time.

Protective features are also included in the control system to take care of the following conditions: (a) Undervoltage and reverse phase, (b) false prime, (c) failure to prime, (d) incomplete starting sequence, (e) overcurrent in main supply line, (f) overheated motor windings of main- and priming-pump motors, (g) overheated bearings, (h) excessive vacuum, (i) simultaneous starting of main motors following power restoration after failure, (j) flooding of pump room, (k) burst of discharge line, and (l) water ceasing to flow in discharge line.

Description of Operation of Automatic Control

General

The circuit design and the scheme of automatic control for the three pumping units in operation at this plant and for the fourth unit to be installed are primarily the same. A description of the operation of unit No. 1 in the south pump room and of the electrical interlocking of the four units will cover the operating principles of the entire pumping plant. The elementary circuit diagram for the control of this unit is shown in figure 1.

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The control equipment is enclosed in sheet-metal cabinets, which are solidly connected to ground. These cabinets insure complete protection to the operating and maintenance personnel against accidental contact with high potential. All units are fully insulated, with no exposed live parts. Figure 2 shows the steel cabinets and control panels for the south pump room. Figure 3 is a general over-all view of the south pump room.

With automatic operation, two forms are available: (a) Continuous, fully automatic operation after the starting impulse has been given, the pumps starting and stopping in the desired sequence in accordance with the water level; and (b) starting and stopping at predetermined times with a time clock, with full-automatic operation within the time limits. When water-inflow conditions permit, use of the time clock restricts operation of pumps to the off-peak period at night.

Suction-head and suction-lift operations are also dependent on inflow conditions. Normally, when the inflow is comparatively light the pumps can be operated under suction head to reduce the total head of discharge. This provision in the control system is used very seldom because when the sump level is above the center line of the pumps it is inadvisable to shut down the pumps except in case of necessity. When the sump level is below the center line of the pumps they are operated on suction lift by throwing a transfer switch, whereby all pumps can, if necessary, operate in accordance with the time-switch settings.

In the circuit diagram (fig. 1) the position of each transfer switch is shown for the following assumed conditions:

1. The manual-automatic switch 43 is set to "automatic" position.

2. The pump-room selector switch 10X is set to a position that selects a south-north pump-room sequence. With switch 10X in this position, both units in the south pump room must be in operation before either unit in the north pump room can be started.

3. Each unit selector switch 10 is set to a position that selects a 1-2 unit sequence for the south pump room and a 3-4 unit sequence for the north pump room.

4. Water in the sump is at a suction-lift level and sufficiently high to close mercoid pressure switch 1-1A.

5. The suction-head suction-lift switch 43S is set to the suction-lift position; therefore, contact 43S-A1 is closed.

6. The time-clock auxiliary switch TSX is set to the "time" position, which inserts the master time clock TS into the circuit.

7. The impulse to start the pump will be given by the time clock at a predetermined time, provided the float switch contacts are closed.

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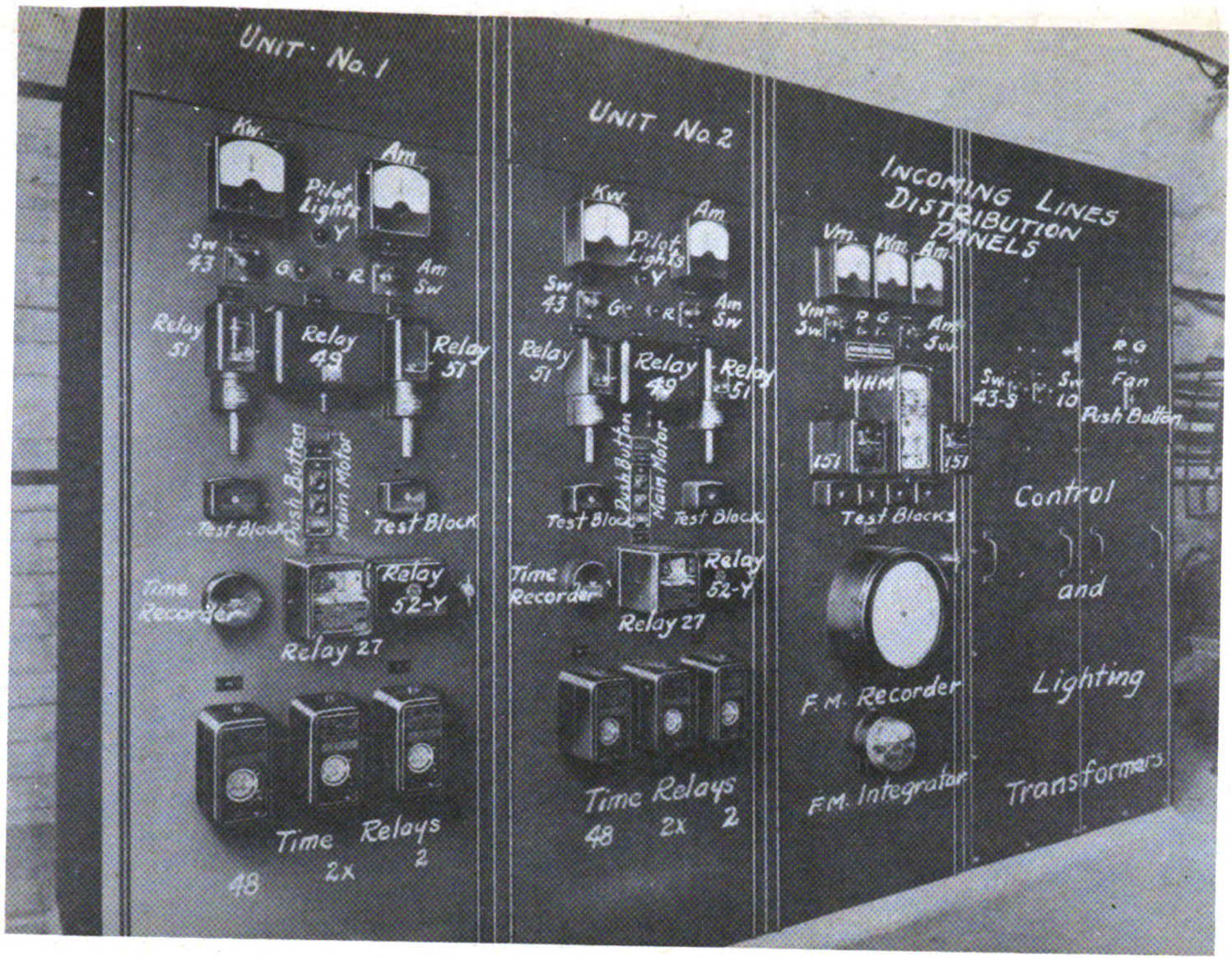

Figure 2. - Control panels for south pump room, case I.

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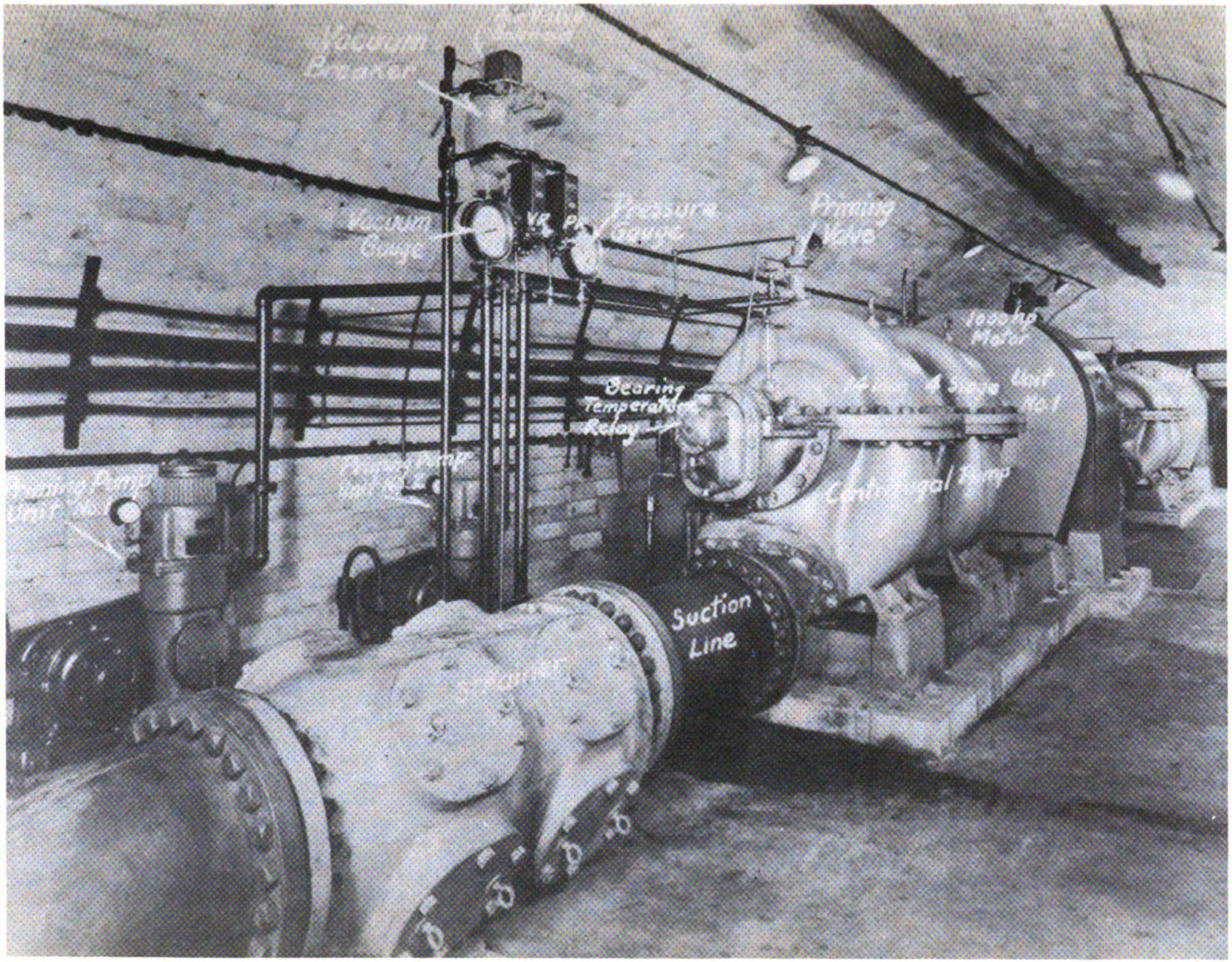

Figure 3. - General view of south pump room, case I.

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Starting the Control Sequence

By reference to figure 1, it is seen that the 220-volt control bus is energized by manually closing the control switch 8. A circuit is completed from the X bus through contact 52-2 through the green light to the Y bus. The green light alone indicates control power is "ON," but the control equipment is not energized.

Time clock TS runs continuously from the 220-volt control bus. At a predetermined time, contact TS-1 closes; thus, a circuit is set up through contacts 10-A2, TS-1, 43S-A1, 1-1A, 10-B3, 43-A1, 10X-A1, and 52-4 to energize the holding coil HC and timing motor TM of relay 2 and the holding coil HC of relay 2X. The instantaneous closing contact 2X-3 closes to light the red pilot light. Both red and green pilot lights are now "ON" at this stage of the cycle, indicating that the control equipment is operating.

Starting the Priming-Pump Motor

The priming-pump motor circuit is energized through an auxiliary contact of circuit breaker 52; thus, the priming pump cannot be started when the main pump is energized.

In the event of an unsuccessful start of the main motor, it is necessary that the main-pump impeller be allowed to come to rest to prevent a false prime on the next priming attempt. This is accomplished by time relay 2, which starts timing when the power is shut off the main motor after a false start. It is set for a time interval of 10 to 15 seconds greater than the time required for the pump impeller to coast to a standstill. The priming pump cannot restart until the expiration of the time set for relay 2, which in this case is approximately 40 seconds. If the pump impeller does not come to rest between starts, water that still remains in the pump casing is thrown toward the periphery of the impeller, whence it is drawn through the priming valve into the vacuum-breaker chamber and prematurely starts the main motor. This is known as a false prime. By insuring that the impeller comes to rest after a false start, the normal process of priming is assured.

The operation of the control circuit for this step is as follows: At the expiration of time set for relay 2, contact 2-TC2 closes to establish a circuit from the X control bus through switch 8; contacts 10-A2, TS-1, 43S-A1, 1-1A, 10-B3, 43-A1, 10X-A1, 52-4, and 2-TC2; relay PP; and contacts 49V-1 and 52HR-1 to the Y control bus.

Relay 2X starts timing as soon as the primer starts. In case some fault, such as a leak in the suction line, prevents normal priming, contact 2X-TC2 closes to energize 52Tr.CHR, which opens 52HR-1 to shut down the primer and closes 52HR-2 to sound the alarm.

Starting the Main-Pump Motor on Temporary Circuit and Stopping Priming-Pump Motor

When the air in the main pump is sufficiently rarefied, water enters through the main suction line, fills the main-pump casing, and rises into the vacuum-breaker float chamber. The water rising in the float chamber

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raises the float, which closes two vacuum-breaker contacts. By this action the main circuit breaker closes and starts the main pump on a temporary circuit, the priming-pump motor is shut down, and time relay 48 is connected in the circuit. Relay 48 has two functions: (a) To limit the number of times the main pump can be successively primed and (b) to shut down the main pump in case the vacuum breaker fails to drain, so as to insure that the pump will not continue to operate without protection. Simultaneously with closing the vacuum-breaker contacts, the vacuum breaker starts to drain, which is indicated by a yellow pilot light.

The operation of the control circuit for this step is as follows:

1. Relay 27 (operating coils not shown on circuit diagram fig. 1) is an undervoltage open-phase and reverse-phase relay that is energized across the secondary of the instrument potential transformers. Its contact, 27-1, is kept closed as long as normal voltage and phase relations exist on the main 2,300-volt bus. The undervoltage device 52UVD is temporarily energized through contacts 52-6, 27-1, and 52HR-1 to the Y bus. Thus, the circuit breaker 52 cannot close to start the main motor until 52UVD has picked up, indicating normal voltage and phase relations on the 2,300-volt bus.

2. Contact VB-2 closes a temporary circuit to energize circuit-breaker 52 motor, which closes the main circuit-breaker 52 and starts the main motor.

3. Contact 52-4 opens to de-energize relays 2 and 2X, which reset themselves for another operation.

4. Priming-pump motor starter PP is de-energized, which shuts down the primer.

5. Contact 2X-3, which has energized the red pilot light up to this point, opens; simultaneously, contact 52-1 closes to maintain the red light, and contact 52-2 opens to de-energize the green pilot light. Thus, it is indicated that the main-pump motor is running.

6. Contact 52-3 closes to energize relay 52Y.

7. Contact 52-6, which has kept 52UVD energized up to this point, opens; simultaneously, contact 52-5 closes to form a part of the permanent circuit to keep 52UVD energized during normal operation of the pump.

8. Contacts 52-bb1 and 52-bb2 open and de-energize circuit-breaker 52, closing motor.

9. When the vacuum-breaker chamber is filled with water, contact VB-1 closes to energize auxiliary relay VBX.

10. Contact VBX-2 closes to energize the timing motor, TM, of relay 48.

11. Contact VBX-1 closes to energize the yellow pilot light and an air valve solenoid AV. This solenoid valve breaks the vacuum and permits the vacuum-breaker chamber to drain. The yellow pilot light indicates that draining is taking place.

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Running Main-Pump Motor on Permanent Circuit

As soon as the main pump begins to function and water starts to flow, the contacts on the check valve CV close, which, together with the pressure regulator contacts, PR, and the vacuum regulator contacts, VR, provide a circuit through the operating coil of the undervoltage device 52UVD. This keeps the oil circuit breaker closed and main-pump motor running. Device 52UVD is provided with a time-delay trip for the main breaker 52. The reasons for the time delay are (a) to guard against tripping the breaker on voltage dips of short duration, owing to starting successively the various pumps, and (b) to insure that the motors already running will not be stopped by the opening of their PR contacts owing to surges in the discharge line by the starting of an additional pump. The other contacts of the check valve CV energize the time recorder, T. Rec., which makes a record of the time the pump is actually pumping water.

The vacuum-breaker chamber starts draining as soon as the priming pump shuts down. Ordinarily, the main pump will attain full speed and pressure, and PR-1 and CV-1 will have closed before the vacuum chamber drains, which requires about 15 seconds. When the chamber has drained, contact VB-2 opens, which breaks the temporary circuit. Contact VB-1 opens to de-energize relay VBX, which, in turn, de-energizes the air valve solenoid and the yellow pilot light, indicating that the vacuum-breaker chamber has drained and that the pump is operating under the protective circuits described above.

If the permanent running circuit described in the preceding paragraph has not been established in the period required for the vacuum chamber to drain, contact VB-2 opens to de-energize 52UVD, trip circuit breaker 52, and shut down the main motor. The control circuit, however, remains energized through contact 52-4 and will make another attempt to start the main pump. This restarting procedure will continue until the attempt to start the main motor has been successful or until the expiration of the time setting of relay 48. In the latter case, contact 48-TC2 closes and energizes 52Tr.CHR to trip the breaker, shut down the main motor, and sound an alarm. This requires a manual reset.

If the vacuum breaker fails to drain, VB contacts will not open and the pump will be operating without the protection of PR, VR, and CV. In this event, also, relay 48 times out, shuts down the main motor, and sounds the alarm, similarly to the above.

Interlocking of the Controls of the Four Pumping Units

Combinations of Unit Starting Sequence for Four Units

The automatic control described in the preceding paragraphs assumed that the selector switches 10 and 10X were set in position to permit a unit starting sequence of 1-2-3-4, in the order named. Other combinations of unit starting sequence can be achieved by changing the settings of switches 10 and 10X, so that any one of the four units can be made to start first and the other three in the desired sequence.

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In addition to the various starting sequences controlled by switches 10 and 10X, the four auxiliary relays 52Y prevent more than one unit from starting at the same time. The manner in which this is accomplished can be seen by reference to figure 1.

Reasons for Control Interlocking

The reason for varying the starting sequence is to equalize the operating time and consequent wear of the four units. This is particularly true during seasons of low inflow, when the pumps are operating on suction lift and are controlled by sump-water elevation, at which times it is possible that only one or two would ever come into service. The reason for preventing more than one unit from starting at the same time is to avoid excessive power peaks on the supply system.

Manual Operation of Main-Pump and Priming-Pump Motors

In order to place the main- and priming-pump motors under manual control, switch 43 is provided. With switch 43 set to the "manual" position, starting and stopping is accomplished through the start-and-stop push-button 1-PB. After pushing the start button, the starting operation for the motors proceeds automatically. Contact 48-3 picks up instantly, sealing in the start circuit around the start button and permitting the start button to be released.

Description of Protective Features in the Control

General

The protective devices used in the control of the 1,000-horsepower pump motor are of two general classes, as follows:

1. The class that functions in the event of a fault that may be only temporary and that, consequently, justifies an additional attempt to place the pumping unit in operation. This class functions through the oil-circuit-breaker undervoltage device 52UVD, which, when de-energized, trips the breaker but leaves the control bus energized and ready for another start.

2. The class that functions in the event of a fault that requires the services of an attendant or maintenance man. This class functions through the oil-circuit-breaker trip coil 52Tr.CHR, which, in addition to tripping the circuit breaker, operates a set of hand reset contacts, 52HR. These contacts shut down the pump, sound an alarm, and lock out the control, so that a manual reset is required before another start is made. Contact 52HR-1, in one leg of the control circuit, is normally closed and opens with the tripping action of 52Tr.CHR, thus locking out the control. Contact 52HR-2 is normally open and closes with the tripping action of 52Tr.CHR, thus completing a circuit through the alarm device. One manual operation reopens contact 52HR-2 and recloses 52HR-1, thereby de-energizing the alarm device and re-establishing the control circuit for another start.

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In the description of the various protective devices, the methods of tripping the circuit breaker will be distinguished by reference to 52UVD or 52Tr.CHR, and the resulting effect upon the control will be as explained in the preceding paragraph. One exception to this is device 27,3/ which prevents the circuit breaker from being closed unless normal voltage and phase relations exist on the 2,300-volt bus.

False Prime (Relay 2)

If the priming pump is started when the main pump is in motion, any water that may be in the pump casing will be thrown by centrifugal action to the periphery of the impeller and drawn up into the vacuum-breaker float chamber, thus closing the vacuum-breaker contacts and prematurely starting the main pump; hence, time-delay relay 2 is provided to insure that the main pump is at a standstill before the priming pump can start. After a predetermined time, contact 2-TC2 closes to energize PP, which, in turn, starts the priming-pump motor. This protective feature does not involve tripping 52Tr.CHR or 52UVD.

Failure to Prime (Relay 2X)

If some fault, such as a leak in the priming system, prevents priming the main pump within a normal length of time, the priming pump would run indefinitely without starting the main pump. To prevent this occurrence, time-delay relay 2X is provided. Relay 2X starts timing when the priming-pump motor starts, and if the main pump is not primed before the expiration of the time setting of 2X, contact 2X-TC2 closes to energize 52Tr.CHR.

Incomplete Starting Sequence (Relay 48)

Relay 48 guards against the continued operation of the pump on the temporary circuit, which does not provide the protection of the pressure regulator, vacuum regulator, and check-valve contacts. The permanent circuit is not established until the vacuum breaker drains. If the vacuum-breaker chamber fails to drain, the vacuum-breaker switch VB remains closed, and relay 48 times out and trips 52Tr.CHR.

Relay 48 also guards against the control equipment attempting an excessive number of starts, the number of attempts being limited to a maximum of four. The VB contacts, which energize the timing element of relay 48, are closed during the draining time, and the time periods registered by relay 48 are cumulative. Therefore, if four attempts are desired, relay 48 is adjusted to a total time equal to four times the draining time of the vacuum-breaker chamber. If, during the total time, a start has not been completed successfully, contact 48-TC2 closes and trips 52Tr.CHR.

Overcurrent Protection (Relays 51 and 151)

Overcurrent protection is provided for all oil circuit breakers. The incoming line breaker is tripped when sufficient overcurrent operates either

3/ Standard adjustment for relay 27 is to close its contacts at 75 percent of rated voltage and to open at 85 percent.

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one or both of the overcurrent relays 151. This sounds an alarm by means of an alarm contact in the oil-circuit-breaker operating mechanism. The incoming-line oil circuit breaker must be closed manually, and this operation opens the alarm contacts. The alarm contacts also may be opened, without closing the breaker, by lowering the operating handle as though to close the breaker, then releasing a connecting-link toggle, and returning the handle to the vertical position. Each motor breaker can also be tripped by means of the current trip coils 52Tr.CHR on sufficient overcurrent to operate either of the two overcurrent relays 51. These overcurrent relays are outside the control circuit and are not shown on circuit diagram figure 1.

Overheating of Main-Motor Windings (Relay 49)

Thermal relay 49 is provided to protect the 1,000-horsepower motor windings against overheating. The thermal elements of relay 49 are heated proportionally to the heating in the motor windings. If the motor-winding temperature reaches a predetermined amount, contact 49-1 closes to energize the shunt trip coil 52Tr.CHR. In addition to the manual reset of 52Tr.CHR, the contacts of relay 49 must be reset manually before a restart is made.

Overheating of Priming-Pump Motor Windings (Relay 49V)

Thermal relay 49V protects the windings of the priming-pump motor. Its normally closed contact 49V-1 is in series with the priming-pump motor starter PP. In case of an overheated motor winding, contact 49V-1 opens to de-energize PP and shut down the primer. In this event, relay 2X times out and trips 52Tr.CHR. Contact 49V-1 must be manually reset before a restart is made.

Overheating of Main-Pump and Main-Motor Bearings (Relay 38)

A bearing thermal relay 38 is provided for each bearing of the main pump and main motor. In case a bearing overheats, contact 38-1 closes to energize shunt trip coil 52Tr.CHR. In addition to the manual reset of 52Tr.CHR., contact 38-1 must be reset manually before a restart is made.

Power Failure (Relay 52UVD)

In case of power failure of greater duration than the time delay of 52UVD (approximately 2 sec.), the main pumps are shut down by the action of 52UVD. Some provision is necessary to prevent two or more motors starting at once when voltage is restored. This is accomplished by the action of the four auxiliary relays 52Y.

Flooding of Pump Room (Relay EFS)

Provision is made to prevent flooding the pump room if the discharge line should break near the top of the shaft. This break might conceivably occur at an elevation such that the discharge pressure would not be reduced sufficiently to operate the PR contact, in which case the pumps would continue to run and would flood the station. To forestall such a possibility, a float switch (not shown on circuit diagram fig. 1) is installed in a

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depression built in the pump-room floor. The switch has a normally open contact, which closes if water rises in this depression to the level of the pump-room floor. Closing the float-switch contact energizes the emergency float-switch coil, which closes its five contacts: One contact (not shown in circuit diagram) lights a set of signal lights in each pump room; the remaining four contacts EFS (one for each pumping unit) close to energize the four-shunt trip coils 52Tr.CHR to shut down all main motors and sound the alarm.

Excessive Vacuum (Relay VR)

In case of excessive vacuum, the vacuum-regulator contact VR-1 opens to de-energize 52UVD and shut down the main motor. The vacuum regulator is adjusted in this case to function only when the suction increases unduly, owing to a blocked strainer. The vacuum-regulator contact is in the permanent running circuit of the main motor, and its functioning will not stop the motor until the vacuum-breaker chamber has drained, breaking contact VB-2 and establishing the permanent circuit through contacts PR-1, VR-1, and CV-1.

Loss of Pressure in Discharge Line (Relay PR)

The pressure regulator contact PR-1 closes when normal pressure has been built up in the main discharge line and opens when this pressure drops to a predetermined amount or fails completely. Loss of pressure may result from (a) restricted inflow of water due to a blocked intake, (b) a broken column line, or (c) entrance of air into the pump through leaky joints in the suction line or through the stuffing boxes on the suction side of the pump.

When the contact PR-1 opens, it de-energizes 52UVD. This PR-1 contact also is in the permanent running circuit of the main motor.

Water Ceasing to Flow in the Discharge Line (Relay CV)

When water ceases to flow in the discharge line, the check-valve contact CV-1 opens. This de-energizes 52UVD and shuts down the main motor. This CV contact is also in the permanent running circuit of the main motor.

CASE II

Description of Pumping Plant

General

This automatic underground pumping plant is located at the bottom of a slope mine approximately 1,600 feet below the surface on the pitch and 370 feet vertically below the surface water level. From the bottom of the main slope a gangway was driven in a westerly direction for a distance of approximately 450 feet. Pump room No. 1 is located at the end of this gangway and is 27 feet long, 21 feet wide, and 10 feet high. Pump room No. 2

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is located outby pump room No. 1 approximately 125 feet and is 33 feet long, 24 feet wide, and 9 feet high. Both rooms are excavated from the right wall of the gangway, facing inby.

Main Pumping Units and Motors

Pump room No. 1 is equipped with one 2,200-g.p.m., 8-inch, 3-stage centrifugal pump known as unit No. 4 and one 1,750-g.p.m., 8-inch, 4-stage centrifugal auxiliary pump known as unit No. 2. Pump room No. 2 is equipped with two 2,200-g.p.m., 8-inch, 3-stage centrifugal pumps known as units Nos. 5 and 6. All units are of all-bronze construction with medium-carbon steel shafts. Units 4, 5, and 6 are driven by 250-horsepower, 2,300-volt, 60-cycle, 1,175-r.p.m. line-start motors with full automatic control. The auxiliary pump (unit No. 2) is driven by a 250-horsepower, 440-volt, 1,175-r.p.m. motor and is not equipped with automatic control. Suction lines are 12-inch cast-iron pipe with bronze strainers and bronze suction bells. The discharge of each pump is connected to a 10-inch cast-iron pipe, into which is fitted an all-bronze check valve with an electric switch. In pump room No. 1 the 10-inch discharge pipe from the 2,200-g.p.m. main pump and from the 1,750-g.p.m. auxiliary pump connects to one 12-inch discharge line, which extends up a 20-degree slope opening for a distance of approximately 1,400 feet to surface water level. In pump room No. 2, the 10-inch pipe from each of the 2,200-g.p.m. main pumps connects to separate 12-inch discharge lines that extend up a second slope opening roughly parallel to the first opening. The three 12-inch lines described above discharge into an open underground tunnel. Water flows by gravity through this tunnel for a distance of 350 feet to the outside and empties into a creek. The slope opening from pump room No. 1 does not terminate at surface-water level but continues up the 20-degree slope for a distance of about 200 feet to the surface. It is through this opening that all main electric power feeders extend from the surface to pump room No. 1.

Electric Power Feeders

Two 3-conductor, 400,000-c.m., 5,000-volt armored cables extend from the surface down the slope opening described above, and tie in parallel to a 2,300-volt bus structure through hand-disconnect pot heads in pump room No. 1. A 3-conductor, 750,000-c.m., 600-volt armored cable extends down the same slope opening and ties through disconnects to supply the 440-volt motor driving the 1,750-g.p.m. auxiliary pump. Three 3-conductor, rubber-covered power cables extend from the 2,300-volt bus structure, one to each of the three 2,300-volt motors driving the 2,200-g.p.m. main pumps.

Auxiliaries

Each pumping unit is equipped with a 50-c.f.m. automatic priming pump driven by a 5-horsepower, 3-phase, 220-volt motor.

Each of the three 2,200-g.p.m. pumping units is equipped with a separate control panel containing automatic controls, metering, and main circuit breaker.

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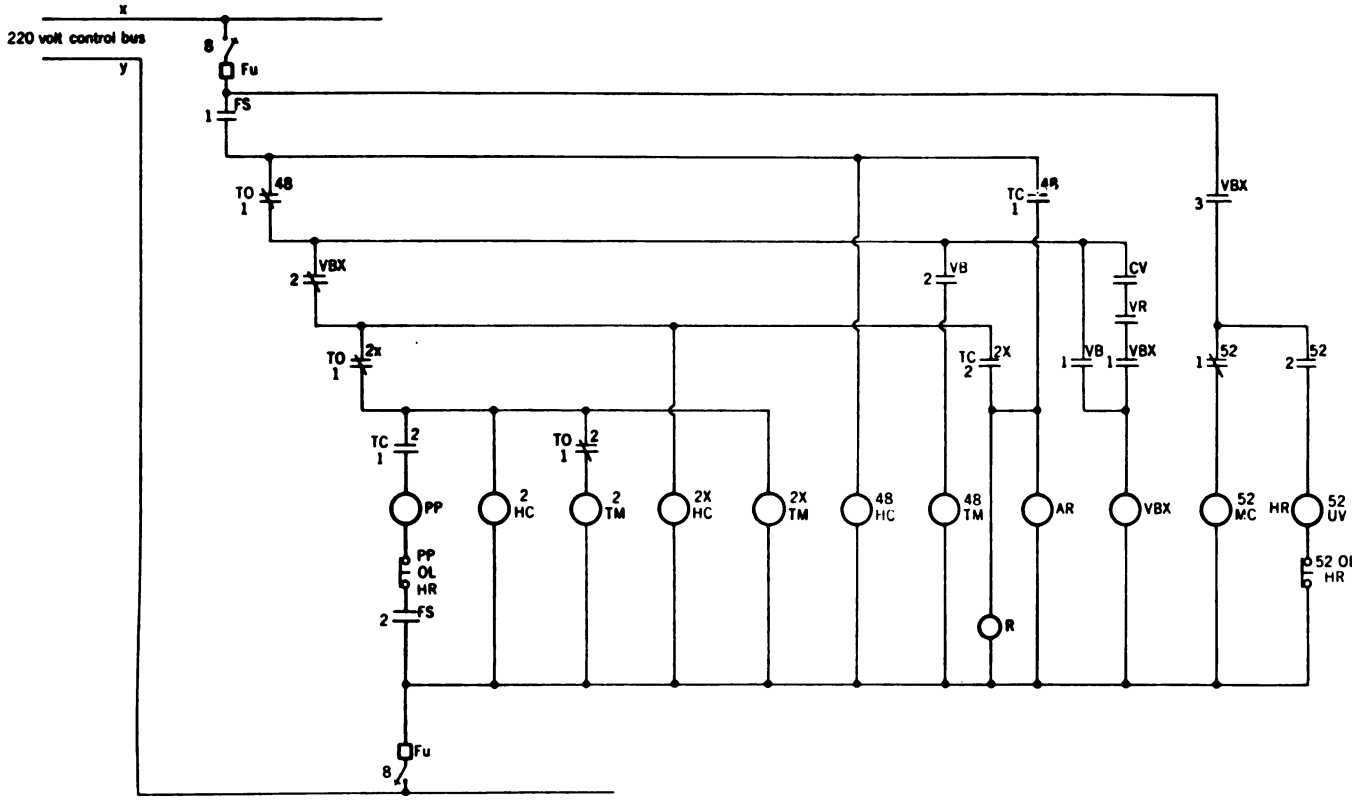

Terminology	
No. //	Device
2	Time delay starting relay
2X	Priming time limit relay
8	Control power switch
48	Incomplete sequence timing relay
52	Main motor oil circuit breaker
Abbr.	
AR	Alarm relay
CV	Check valve
FS	Float switch
Fu	Fuse
HC	Holding coil
HR	Hand reset
MC	Main coil
OL	Overload contact
PP	Priming pump motor starting relay
R	Red lamp
TC	Time close
TO	Time open
UV	Under voltage device
VB	Vacuum breaker
VBX	Auxiliary relay for VB
VR	Vacuum regulator

Graphical symbols //	
Contact Normally open	Contact Normally closed
Contact Time close T. C. Normally open	Contact Time open T. O. Normally closed
coil	Fuse

// In accordance with standards established by the American Standards Association

Figure 4. - Automatic pumping control circuit diagram, case II.

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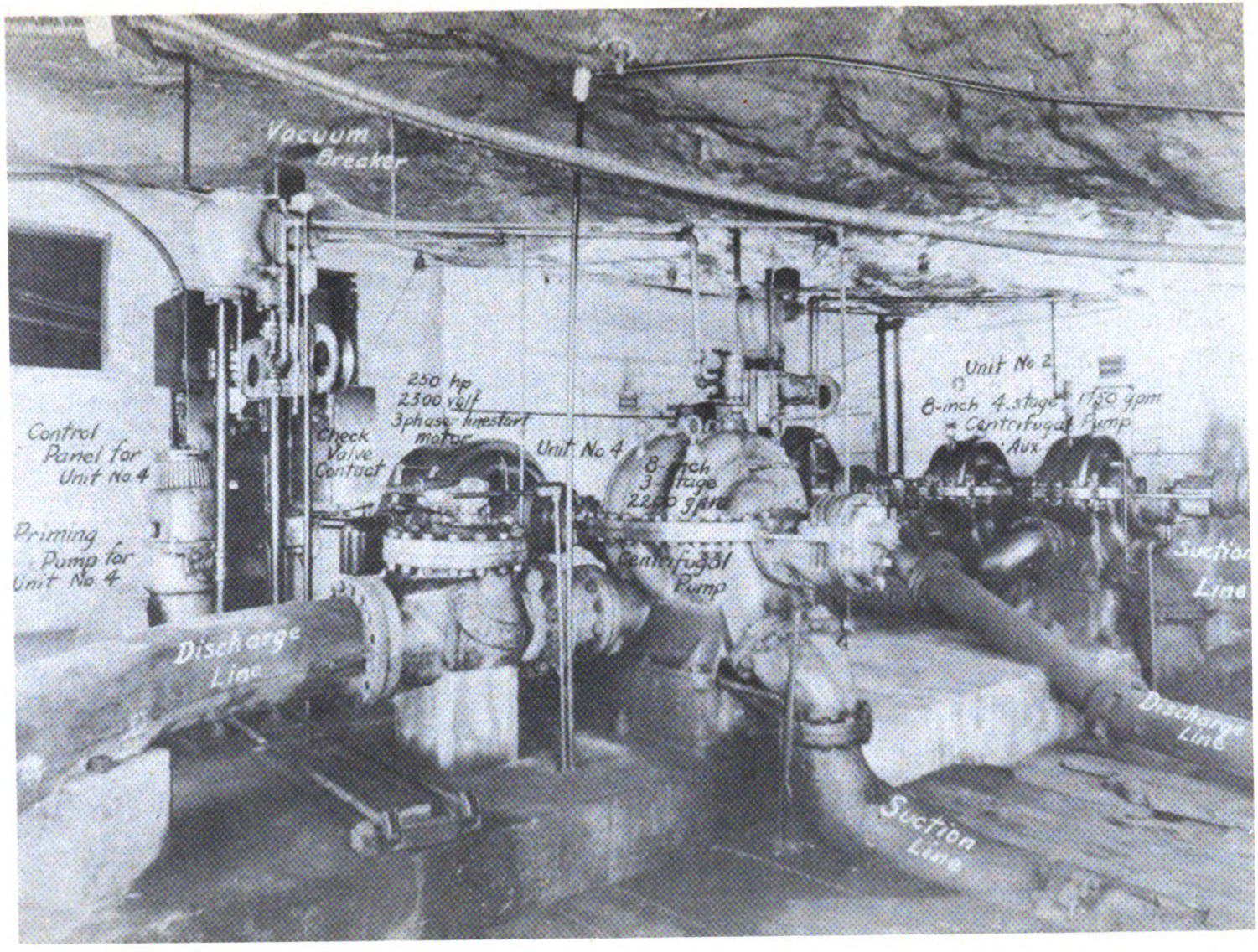

Figure 5. - General view of pump room No. 1, case II.

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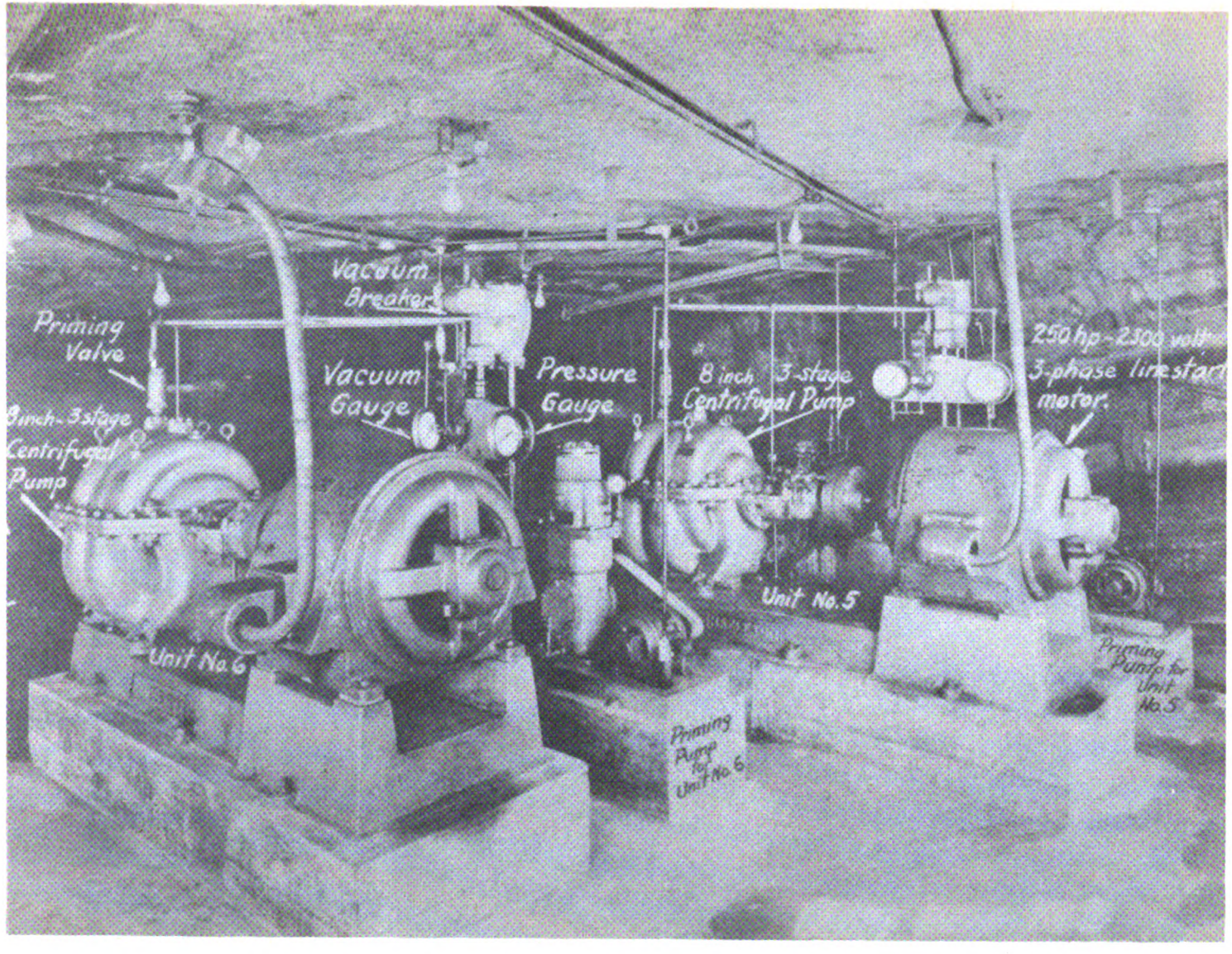

Figure 6. - General view of pump room No. 2, case II.

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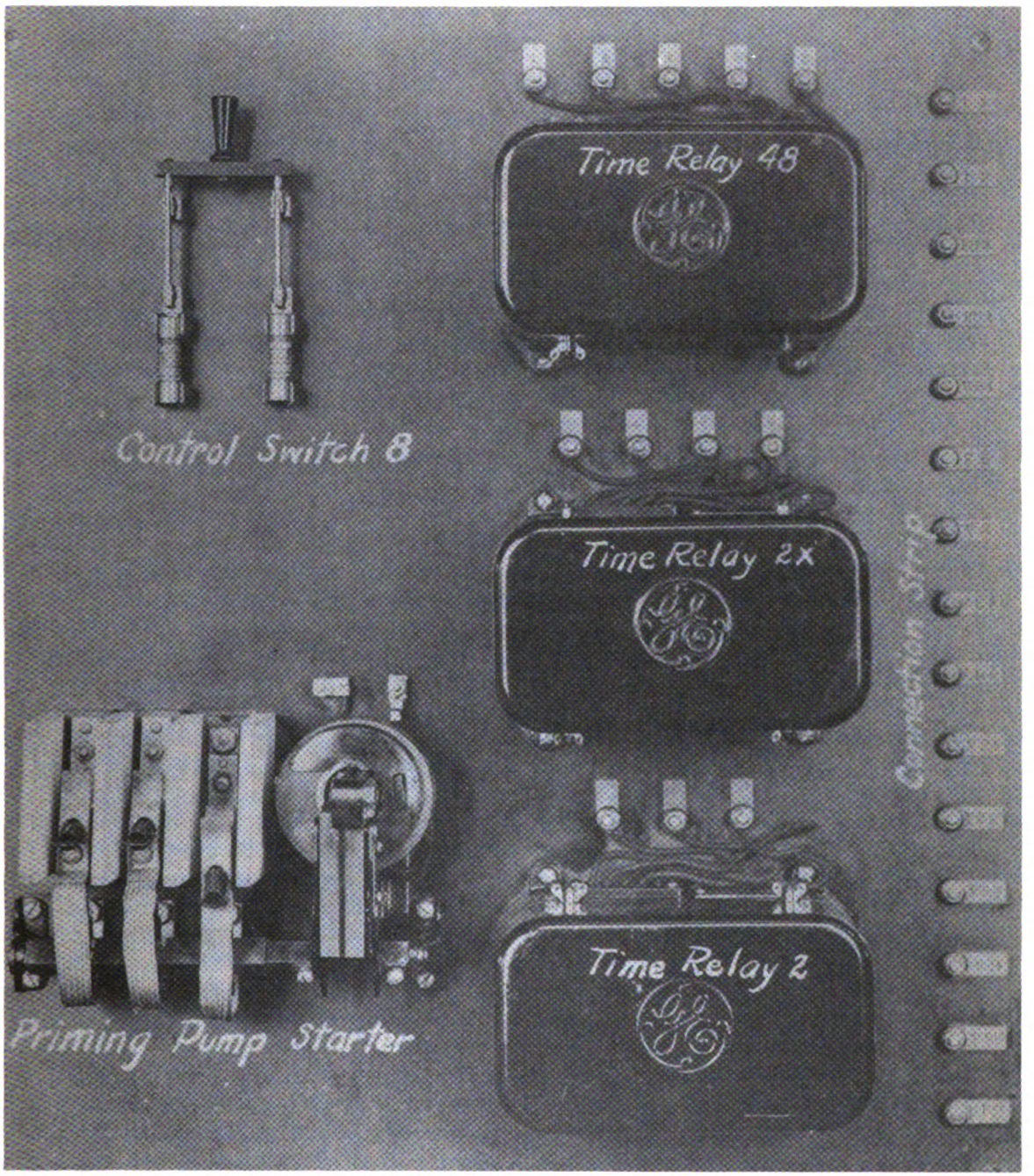

Figure 7. - Automatic relay panel, case 11.

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Two 7-1/2-kv.-a., 2,300/440/220-volt auxiliary transformers are installed in the rear of each control panel and are connected in open delta to supply power to priming pumps, control circuits, and 220-volt lighting.

Metering

One ammeter is provided for each main pumping unit to measure load current taken by each main motor. The ammeter is shifted between phases by means of a jack and plug.

Protective Features

Protective features are included in the control system to take care of the following conditions: (a) False prime, (b) failure to prime, (c) incomplete starting sequence, (d) overcurrent, (e) excessive vacuum, (f) simultaneous starting of main motors following power restoration after failure, and (g) water ceasing to flow in discharge line.

Description of Operation of Automatic Control

General

The design and operation of the automatic control mechanism is the same for all three 2,200-g.p.m. main pumping units, and a description of the operation of any one of them will cover the operating principles of the entire plant. The elementary circuit diagram for the control of unit No. 6 is shown in figure 4. Figures 5 and 6 are general views of the two pump rooms, and figure 7 is a view of the automatic relay panel. Float switches, one for each pump, are set for different levels of water in the sump. When the sump has filled to a predetermined height at which a pump should start, the float switch closes. Thus, operation of each pump is controlled by the setting of its float switch. The only interlocking between pumps is that necessary to permit change of sequence in operation and to prevent all pumps from starting at once when power returns after an interruption and the water level has risen sufficiently to close all the float switches. Change of sequence of operation is accomplished by manually interchanging float switches from one pump to another.

Starting the Priming-Pump Motor

By reference to the circuit diagram (fig. 4), it is seen that the 220-volt control bus is energized by manually closing control switch 8. It is assumed that water in the sump has risen to sufficient height to close float-switch contacts FS-1 and FS-2. Power is thus established from the X control bus through contacts FS-1, 48-TO1, VBX-2, 2X-TO1, and 2-TO1 through the timing motor of relay 2 to the Y control bus. Relay 2 starts timing, therefore, when the float switch closes. At the expiration of the time set on relay 2, contact 2-TC1 closes to establish power to the priming-pump starter relay PP. Relay PP contactors (not shown on diagram fig. 4) close to start the priming-pump motor. The reason for this time delay in starting the priming-pump motor is that in the event the main pumping unit has just

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previously made an unsuccessful attempt to start, it is necessary that the main pump be allowed to come to rest to prevent a false prime on the next priming attempt. When power is shut off the main motor, owing to a false start, contact VBX-2 closes and starts the timing element of relay 2. Relay 2 is set for a time exceeding, by a few seconds, the time required for the pump to coast to a standstill after power is shut off. By thus insuring that the impeller comes to rest after a false start, the normal process of priming is assured.

When the priming pump has sufficiently rarefied the air from the main pump, the normal action of the control is to start the main motor, open contact VBX-2, de-energize relay 2, open contact 2-TC1, and shut down the priming-pump motor. In case some fault, such as a leak in the priming suction line, prevents this normal priming, another circuit is set up to limit the time the priming-pump motor will run, shut down the primer, and sound an alarm. This is accomplished by time relay 2X, which is energized at the same time relay 2 is energized. If the main pump does not prime normally, relay 2X times out. Contact 2X-TO1 opens to de-energize relay PP, which shuts down the primer, and contact 2X-TC2 closes to energize the alarm.

Starting Main-Pump Motor on Temporary Circuit and Stopping Priming-Pump Motor

With normal priming, water enters through the main suction line, fills the main-pump casing, and rises up through the priming valve into the vacuum-breaker float chamber. The water rising in the float chamber raises the float, which closes two vacuum-breaker contacts. By this action the main-pump motor is started through a temporary circuit, and the priming-pump motor is shut down. Also, time relay 48 is energized. The function of relay 48 is to (a) limit the number of times the main pump can be restarted successively and (b) to shut down the main pump in case the vacuum breaker fails to drain, which insures that the pump will not continue to operate without protection. Simultaneously with the closing of the vacuum breaker contacts, the vacuum breaker starts to drain.

The relay operations to accomplish the above steps are as follows:

1. As the vacuum-breaker chamber fills with water, contact VB-1 closes to energize auxiliary relay VBX. Contact VBX-1 closes to form a part of the permanent running circuit. Contact VBX-2 opens to shut down the priming-pump motor and reset time relays 2 and 2X. Contact VBX-3 closes to energize the main coil of oil circuit breaker 52MC. The main circuit-breaker contacts (not shown on the diagram, fig. 4) close to start the main motor. As the circuit breaker closes, contact 52-1 opens to de-energize 52MC. Contact 52-2 closes to energize 52UVHR. The circuit breaker is thus held in the closed position by 52UVHR under normal conditions of load and voltage.

2. Contact VB-2 closes to energize the timing motor of relay 48. The timing action of this relay occurs only when the vacuum-breaker contacts are closed.

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3. As the float rises in the chamber, the air valve (not shown on circuit diagram) is mechanically opened, breaks the vacuum, and permits the water to drain. The drain is proportioned so that the vacuum breaker will be empty, the float down, and the switch open in about 15 seconds.

4. On repeated unsuccessful attempts of the main motor to start, the cumulative time registered by relay 48, owing to repeated filling and draining of the vacuum-breaker chamber, will, at the expiration of the total time setting of relay 48, open contact 48-TO1 and lock out all control relays. The total time setting of relay 48 is that which is required for three starts and stops of the main motor. The main motor is shut down when contact 48-TO1 de-energizes relay VBX. Contact 48-TC1 closes to energize the alarm AR. Relay 48 requires a manual reset by opening switch 8.

5. If the vacuum breaker fails to drain while the main motor is running on temporary circuit, relay 48 times out, breaks contact 48-TO1, de-energizes relay VBX, and opens contact VBX-3, which shuts down the main motor. Contact 48-TC1 closes to sound the alarm. This requires a manual reset to restore normal conditions.

Running Main-Pump Motor on Permanent Circuit

As soon as the main pump begins to function and water starts to flow, the check valve CV, in the discharge line, closes to form a part of the permanent running circuit. The vacuum regulator VR is provided with a normally closed single-pole contact, which opens on excess vacuum in the main-pump suction line and closes when the vacuum has returned to normal or less. Contact VR forms a part of the permanent running circuit. Contact VBX-1 is closed because relay VBX is energized. This completes the permanent running circuit. Ordinarily the pump will attain full speed and steady pressure and the CV contact will have closed before the vacuum chamber drains, which requires about 15 seconds. When the vacuum chamber has drained, contact VB-1 opens and breaks the temporary starting circuit. The motor continues to operate through the permanent running circuit.

If the permanent running circuit described in the preceding paragraph has not been established in the period required for the vacuum-breaker chamber to drain, contact VB-1 will open to de-energize relay VBX and shut down the main motor. The control circuit, however, remains energized and will make another attempt to start the main pump. This restarting procedure will continue until the attempt to start the main motor has been successful or until the expiration of the time setting of relay 48. In the latter case, contact 48-TO1 opens to de-energize relay VBX, which opens contact VBX-3 to shut down the main motor. Contact 48-TC1 closes to sound the alarm.

Description of Protective Features in Control

False Prime (Relay 2)

If the priming pump is started when the main pump is still in motion, any water that may be in the pump casing will be thrown by centrifugal action to

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the periphery of the impeller and drawn up into the vacuum-breaker float chamber, thus closing the vacuum-breaker contacts and prematurely starting the main pump. This is known as a false prime. Relay 2 is provided to insure that the main pump is at a standstill before the priming pump can start. After a predetermined time, to allow the main-pump impeller to coast to a standstill, contact 2-TC1 closes to energize relay PP, which in turn starts the priming pump motor.

Failure to Prime (Relay 2X)

If some fault, such as a leak in the priming system, prevents normal priming, relay 2X is provided to prevent the priming pump from running indefinitely without starting the main pump. Relay 2X starts timing at the same time relay 2 starts. If the main pump is not primed before the expiration of the time setting of relay 2X, contact 2X-TO1 opens, breaking the circuit to relay PP and shutting down the priming-pump motor, and contact 2X-TC2 closes to sound the alarm. Relay 2X is hand-reset by opening control switch 8.

Incomplete Starting Sequence (Relay 48)

Relay 48 guards against the continued operation of the pump on the temporary circuit, which does not provide the protection of the vacuum-regulator check-valve contacts. The permanent circuit is not established until the vacuum-chamber drains. In the event that the chamber fails to drain, contact VB-2 remains closed, and relay 48 times out, opens contact 48-TO1, and shuts down the main motor. Relay 48 also guards against the control equipment making an excessive number of attempts to start the main pump, the number of attempts being limited to three. The VB contacts, one of which energizes the timing element of relay 48, are closed during the draining time of the vacuum breaker, and the time periods registered by relay 48 are cumulative. Therefore, if three attempts are desired, relay 48 is adjusted to a total time equal to three times the draining time of the vacuum breaker. If during this total time a start has not been completed successfully, contact 48-TO1 opens and de-energizes relay VBX, which opens contact VBX-3 and shuts down the main motor. Contact 48-TC1 closes to energize the alarm. Relay 48 must be reset by hand by opening control switch 8.

Overcurrent Protection (Relay 52OLHR)

Overcurrent protection is provided for the main motors by means of a thermal overload contact in the main oil circuit breakers. Under conditions of overload on main motor, contact 52OLHR opens, de-energizes 52UVHR, and shuts down the main motor. The circuit breaker requires a hand reset. The alarm does not sound immediately, because the control must first go through a series of attempts to restart the main motor. At the expiration of time setting of relay 48, contact 48-TO1 opens to lock out all relays, and contact 48-TC1 closes to sound the alarm. Relay 48 also requires a hand reset by opening control switch 8.

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The priming-pump motor starter is also provided with overcurrent protection. On overload of the priming pump, contact PPOLHR opens to de-energize relay PP and shut down the priming pump. This contact requires a hand reset before the priming pump can be restarted.

Excessive Vacuum (Relay VR)

In case of excessive vacuum, the vacuum regulator contact VR-1 opens, de-energizes relay VBX, opens contact VBX-1, and shuts down the main motor. By close adjustment, the vacuum regulator will function under certain conditions of a broken discharge line. The break must, however, be of such severity that it causes a sizable increase in pump discharge and increases suction lift sufficiently to operate relay VR.

Simultaneous Starting of Main Motors Following Power Restoration After Failure

In case of power failure or dip in voltage, all main pumps are shut down by the action of 52UVHR, which trips the main breakers.[4] If water in the sump is deep enough to keep the float switches closed, some provision is necessary to prevent two or more motors starting at once after the main circuit breakers are closed by hand and voltage is restored. This is accomplished by setting each relay 2 of the individual pumping units for varying lengths of time. When power is restored to the line, the main pumps will restart in sequence, as determined by the time setting of these relays.

Water Ceasing to Flow in Discharge Line (Relay CV)

When water ceases to flow in the discharge line, the check-valve contact CV opens, de-energizes relay VBX, and shuts down the main motor.

DISCUSSION

Summary of Control Features for Case I and Case II

Case I is an example of a modern, fully automatic, submerged pumping plant. Automatic devices and circuits are installed to provide protection to the extent that if all relays are working properly it is impossible for the pumps to operate unless all conditions are such that operation will be satisfactory. Regular operating personnel are not required except for routine inspection.

Case II is typical of a modern, fully automatic, underground, open-type pumping plant. The automatic control equipment functions similarly, in many respects, to that of case I, summarized below. As in case I, no regular operators are necessary except for routine inspection.

The two pumping plants are provided with automatic control mechanism to protect against the following conditions: Undervoltage on 2,300-volt bus,

4/ Standard adjustment for 52UVHR is to open at 85 percent normal voltage.

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false prime, failure to prime, incomplete starting sequence, overcurrent in main- and priming motor, excessive vacuum, simultaneous starting of main motors following power restoration after failure, and water ceasing to flow in the discharge line. Case I is provided with the following additional control features not included in case II: Protection against flooding the pump room, electrical interlocking of pumping units, pump operation under suction head or suction lift, protection against overheated bearings, and protection against open or reverse-phase conditions.

The control mechanisms common to both case I and case II function similarly, with the following exceptions:

1. Undervoltage on 2,300-volt bus: In case I, each of the four undervoltage devices is equipped with a time-delay trip, of approximately 2 seconds, on the circuit breaker of each main-pump motor. The reason for this is to guard against tripping the circuit breakers and shutting down the main motors on voltage dips of short duration and to insure that the motors already running will not be stopped by the opening of their pressure-regulator contacts owing to surges in the discharge line by the starting of an additional pump. In case II, the undervoltage device operates instantaneously, and any sudden dip in voltage (below 85 percent normal) will trip the circuit breakers, shut down the main motors, and sound the alarm. In both cases the circuit breakers require a hand reset before the main pumps can be started again.

2. Simultaneous starting of main motors following power restoration after failure: In case I, four auxiliary relays 52Y are used to protect against more than one motor starting at the same time in order to avoid excessive power peaks on the supply system. In case II, this is accomplished by setting each relay 2 on the individual pumping units for varying lengths of time.

A summary of the control features provided in case I but not included in case II is as follows:

1. Protection against flooding pump room: This feature is necessary in the submerged-type pump room to prevent the room from flooding in case of a broken discharge line. The pump rooms in case I are also protected by emergency float switches, which serve to shut down the main pumps when any water leaking into the rooms reaches floor level. In the open-type pump room this feature is not necessary. In the event of a broken discharge line, water returns by gravity to the main sump. However, the vacuum regulator in case II is closely adjusted so as to function under a severe break in the discharge line. If the leak is sufficiently large, the increased pump discharge increases the suction lift to operate the vacuum regulator and shut down the main pump.

2. Electrical interlocking of all units: In case I, all units are interlocked by transfer switches 10 and 10X to control the starting sequence. In case II, the float switches are interchanged manually when it is desired to change the starting sequence.

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3. Pump operation either with suction head or suction lift: This feature is necessary in a submerged-type pump room. In the open-type pump room water in the sump is always at a suction-lift level.

4. Bearing temperature relays for all main-motor and main-pump bearings: This protective feature is useful where water conditions are such that it is inadvisable to shut down the pumps for preventive maintenance, such as in case I.

5. Protection against open- or reverse phase on main line: The open-phase protection prevents the motor from operating single-phase, and thus overheating, in the event one of the line wires is opened. The reverse-phase protection prevents the motor from starting up in the wrong direction in the event any two of the line wires are reversed.

It has been seen that the basic essential control mechanisms for protection against faults common to both pumping plants function in a somewhat similar manner regardless of the source of design and manufacture. Only by disseminating information on the design and operation of various modern pumping plants can control design for future installations be standarized. This standardization will benefit the industry by simplification in design and by lower installation and maintenance costs.

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